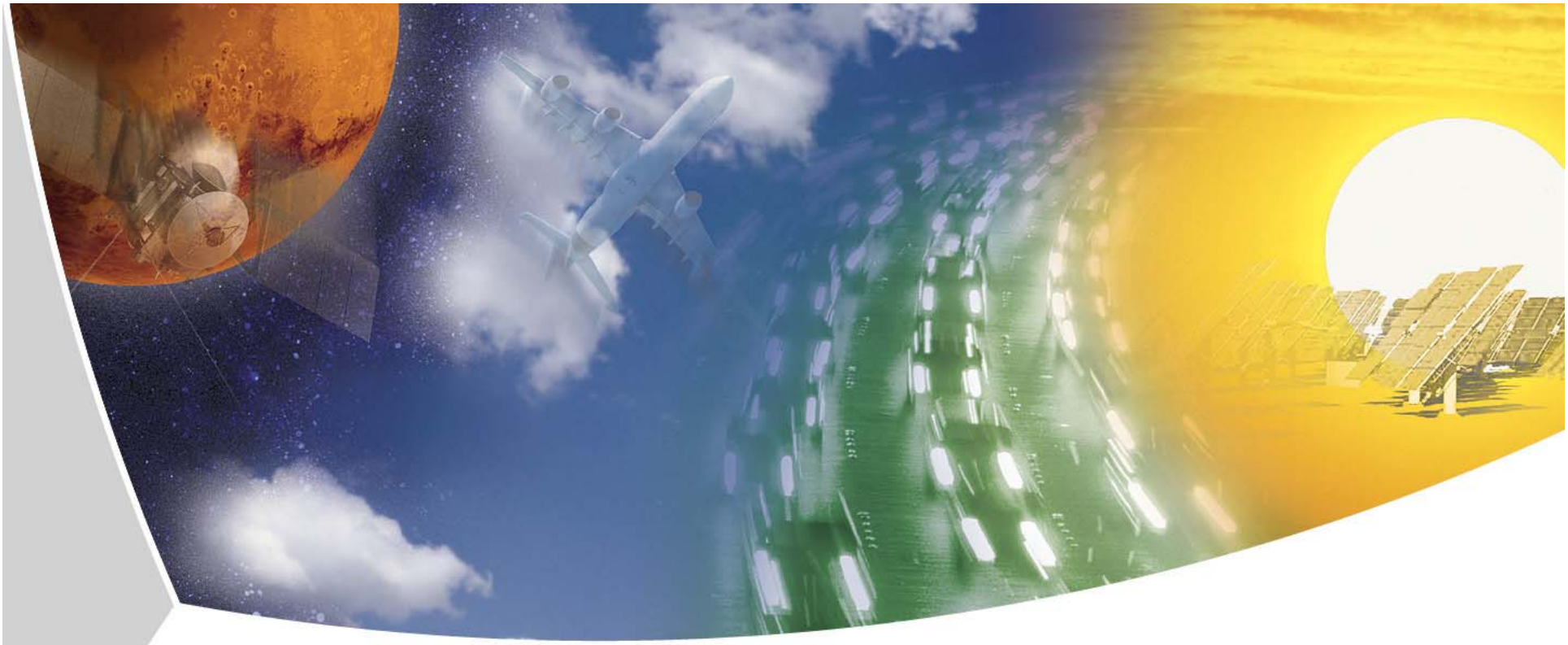

SOFC Development and Characterisation at DLR Stuttgart

G. Schiller

German Aerospace Center (DLR)
Institute of Technical Thermodynamics

2nd Indo-German Workshop on Fuel Cells and Hydrogen Energy, Karlsruhe, March 17-19, 2009

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

The DLR
German Aerospace Research Center
Space Agency of the Federal Republic of Germany

Sites and employees

5.600 employees working in 28 research institutes and facilities

- **at 8 sites**
- **in 7 field offices.**

Offices in Brussels, Paris and Washington.

DLR Stuttgart


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Administration and Infrastructure
Dipl.-Wirt.Ing. J. Piskurek
Logistics & Purchasing
Project Administration
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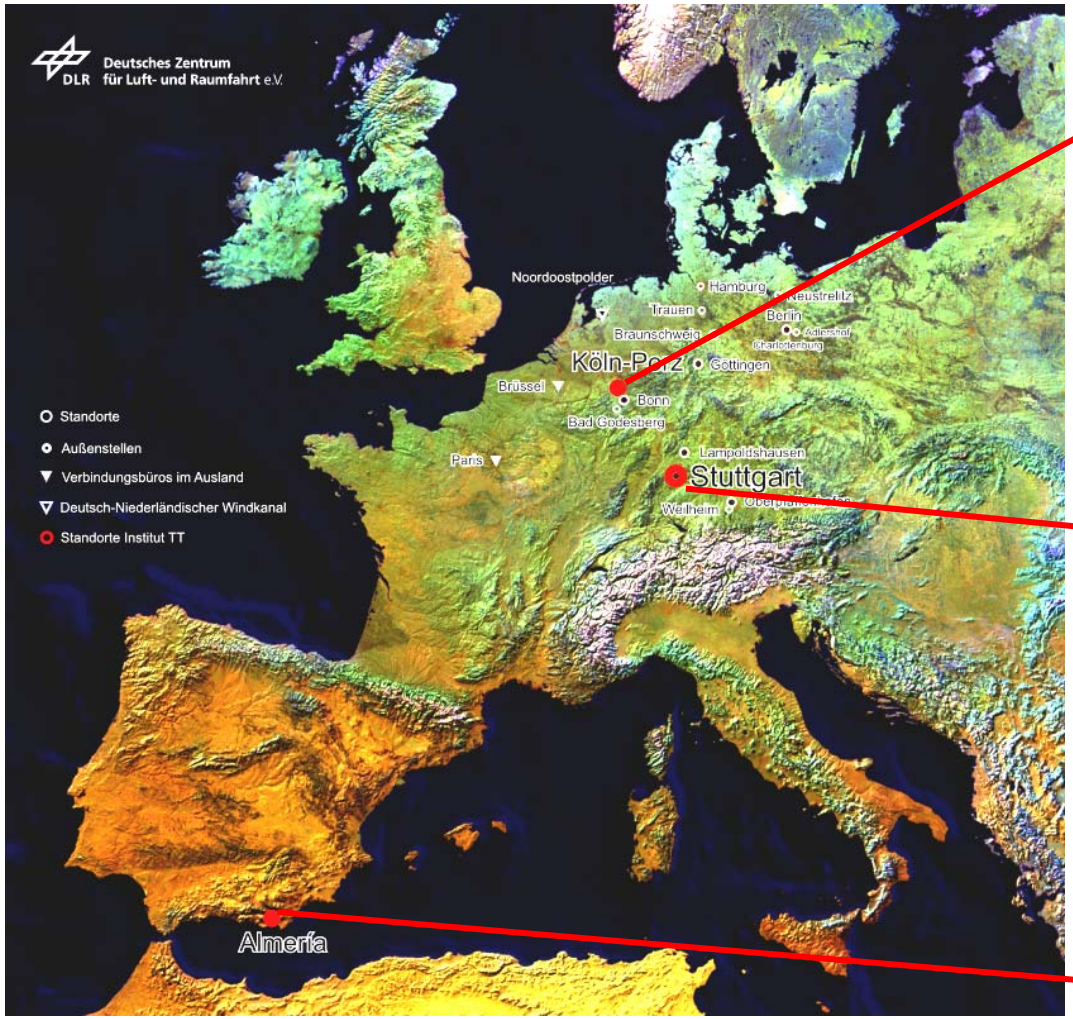
Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
Standorte
Außenstellen
Verbindungsbüros im Ausland
Deutsch-Niederländischer Windkanal
Standorte Institut TT
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Hamburg
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Charlottenburg
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Göttingen
Brüssel
Bonn
Bad Godesberg
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Stuttgart
Weilheim
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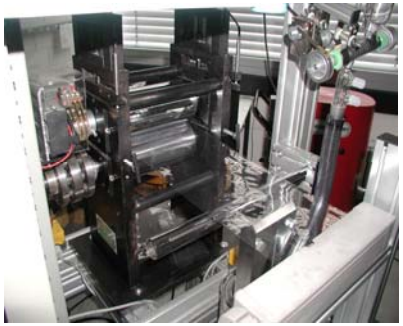
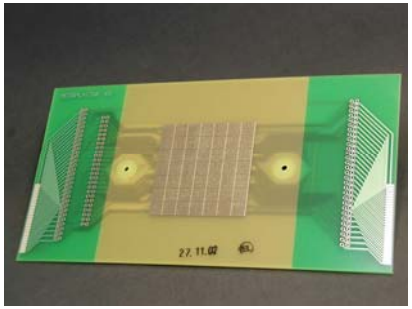
DLR Institute of Technical Thermodynamics

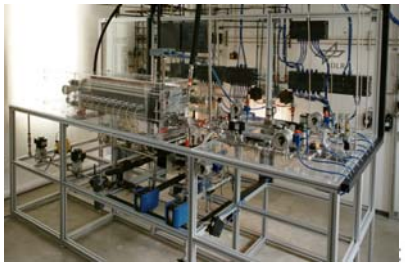
Low Temperature Fuel Cells
AFC, PEFC, DMFC



MEA production



Segmented Cells for analysis and control



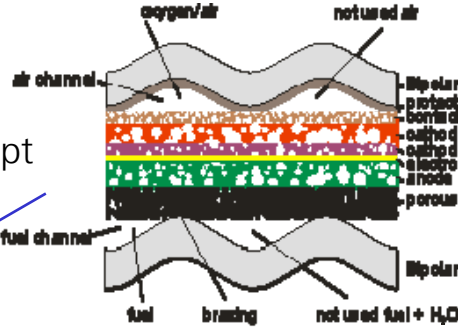
PEMA Test equipment

Fuel Reforming

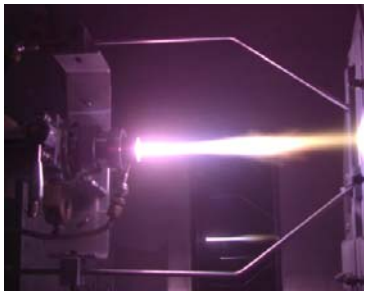
Competence and Activities

System Technology and Analysis

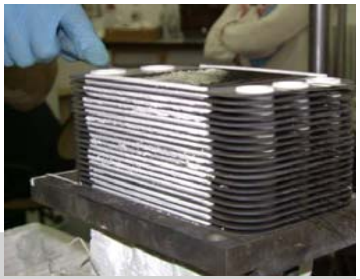
Spray Concept



Plasma deposition process



SOFCs for APUs

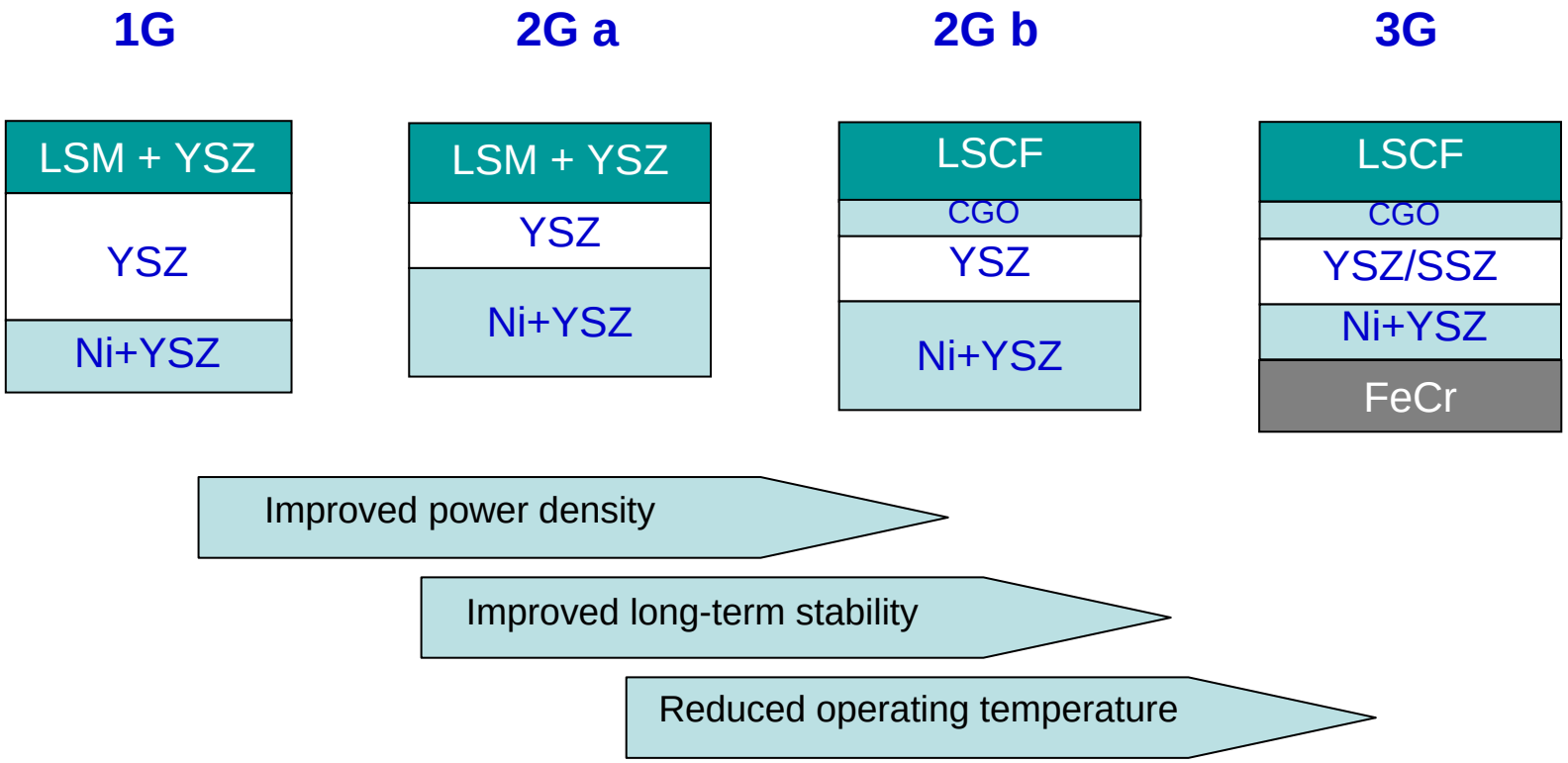


e.V.
in der Helmholtz-Gemeinschaft

Outline

- Introduction
- Development of SOFC Spray Concept of DLR
  - Development of Cells and Functional Layers
  - Electrochemical Cell Performance
- Spatially Resolved Cell Characterisation and Modelling
- Conclusions

SOFC Development from 1st (1G) to 3rd Generation (3G)



Advantages of Metal Supported Cells (MSC)

- High electrical conductivity of the metal support
- High thermal conductivity of the metal support
- High stability of the cell during temperature changes
- High and homogeneous mechanical stability of the cell
- Application of conventional joining and sealing techniques
- Cost reduction for materials and fabrication technologies

SOFC Spray Concept of DLR

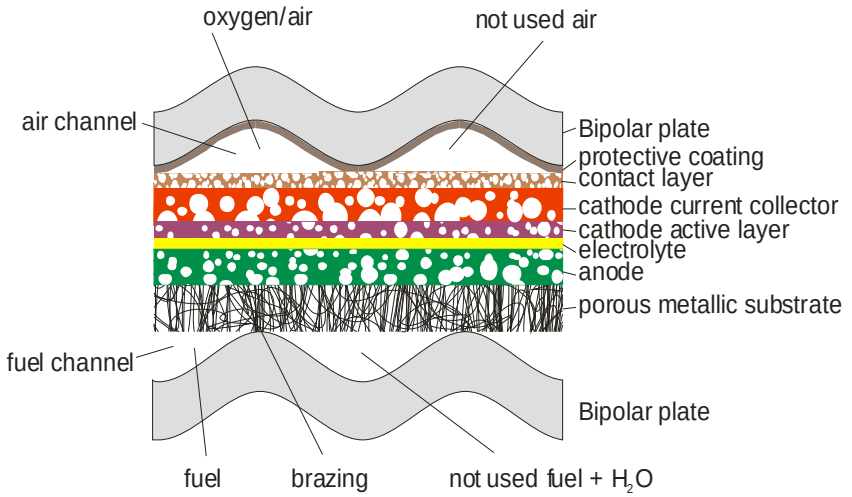
Plasma Deposition Technology

Thin-Film Cells

Ferritic Substrates and Interconnects

Compact Design with Thin Metal Sheet Substrates

Brazing, Welding and Glass Seal as Joining and Sealing Technology



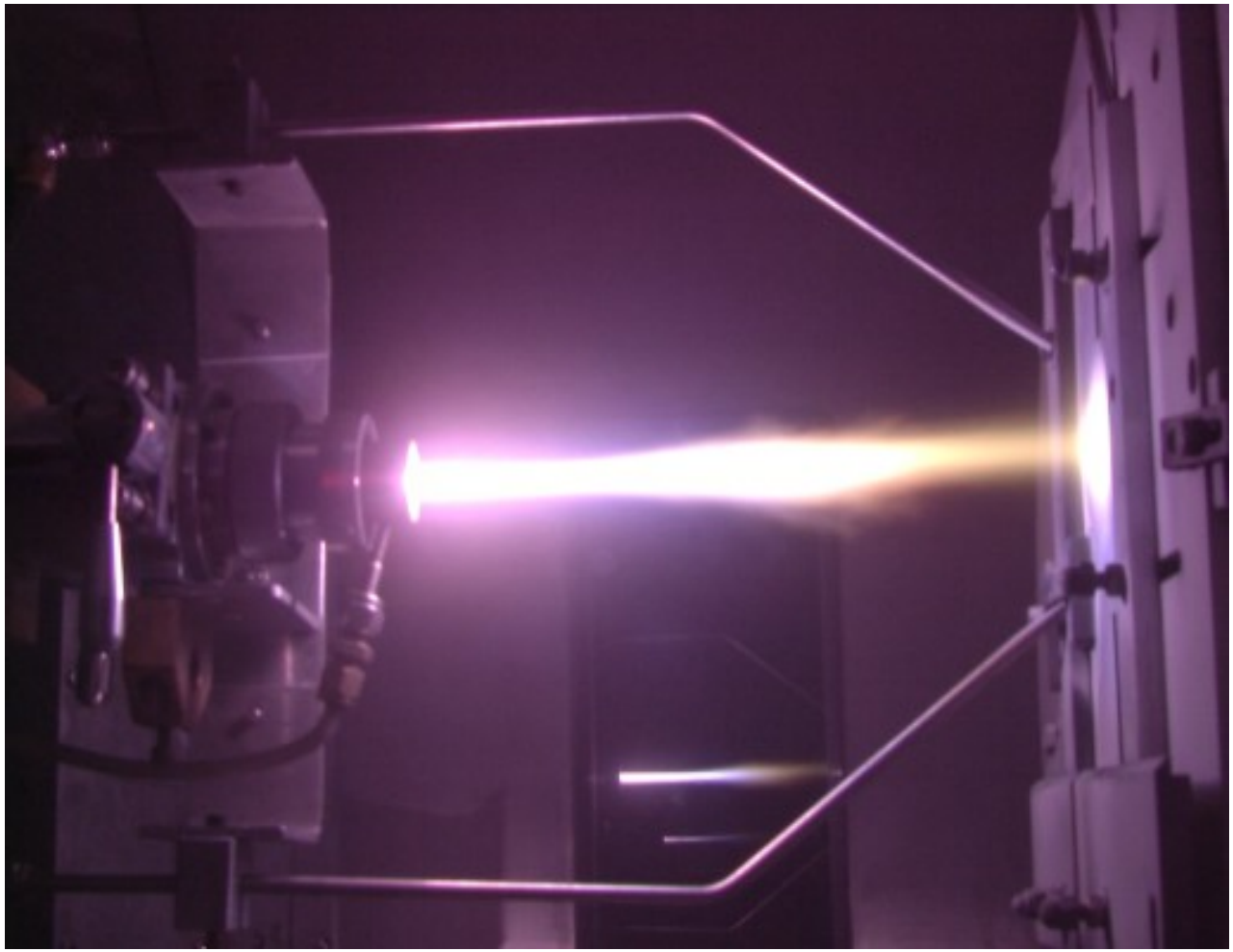
(not in scale)

Schematic of DLR-SOFC Design with Metallic Substrate

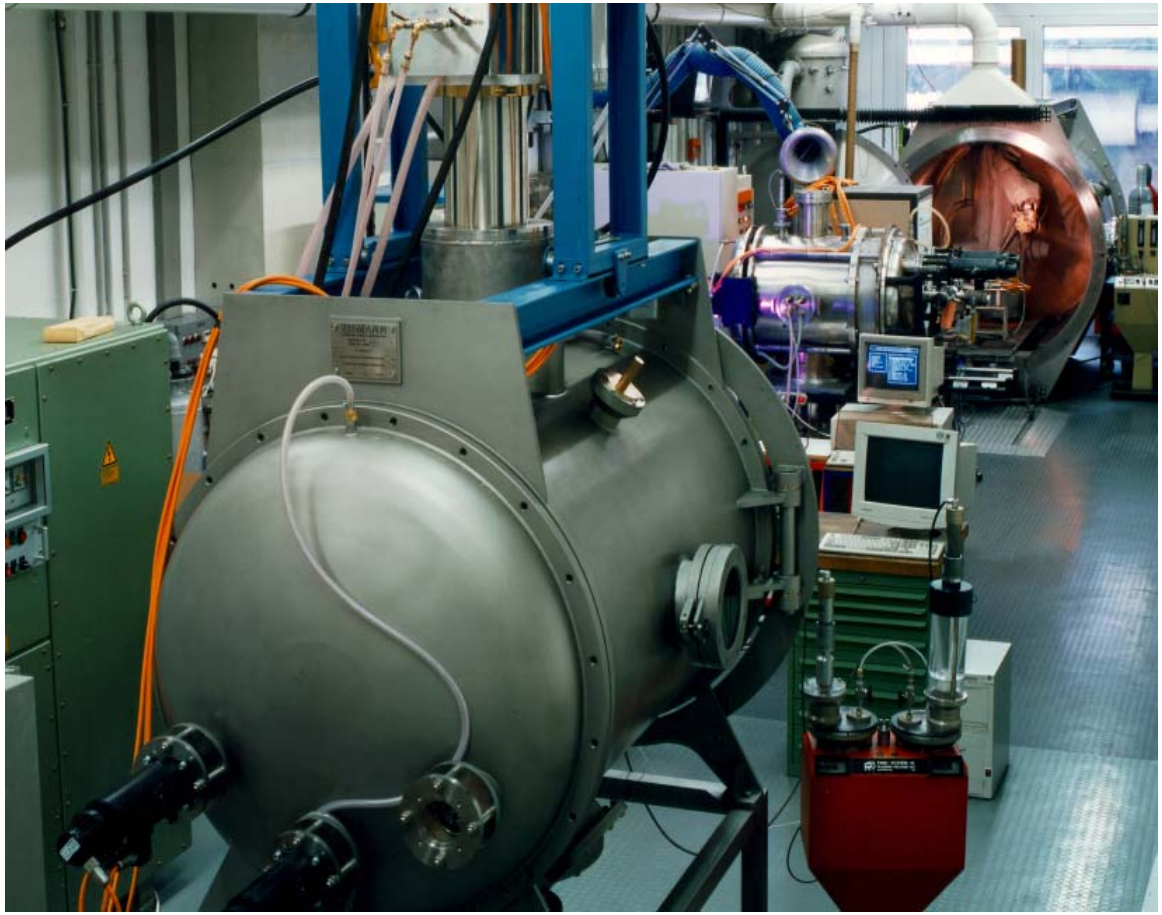
Objective of DLR Development:

Light-weight stack of 5 kW power with high performance, rapid heat-up and good thermal cycling properties

Vacuum Plasma Spraying of SOFC Cells

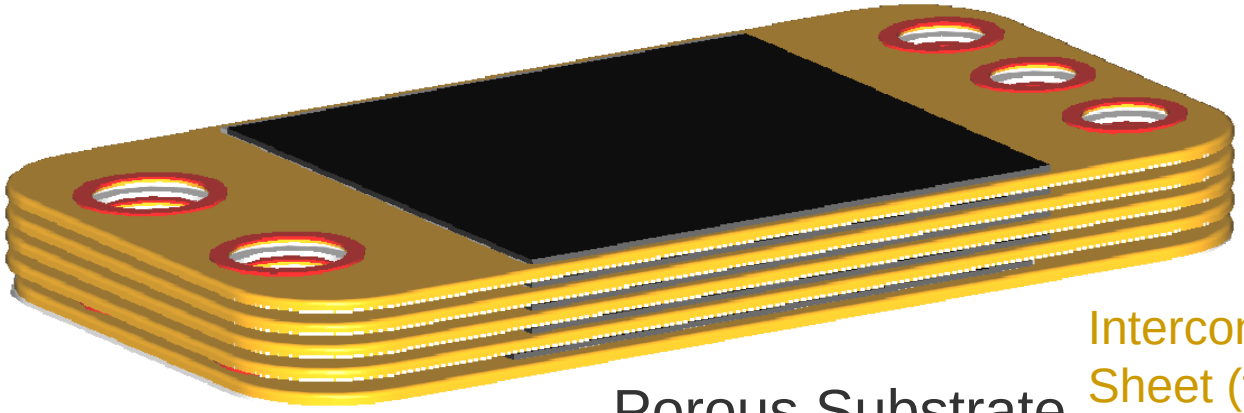


Plasma Spray Laboratory at DLR Stuttgart



VPS Pilot Facility at DLR Stuttgart

DLR Plasma Spray SOFC Concept (Mobile Application)



Cathode Contact Layer

Seals

Cell Layers

Interconnect Sheet (top)

Porous Substrate

Stamped Interconnect Sheet (bottom)

Development Project Metal Supported SOFC

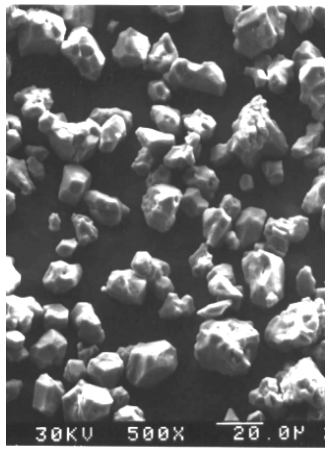
Plansee GmbH, Sulzer Metco Coatings GmbH, ElringKlinger AG and DLR

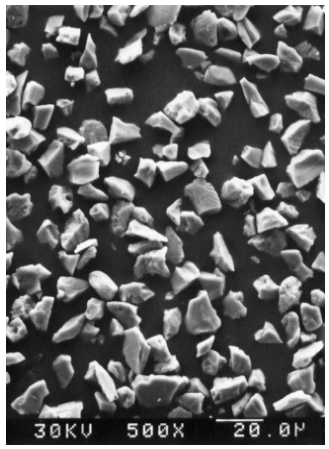
Objectives:

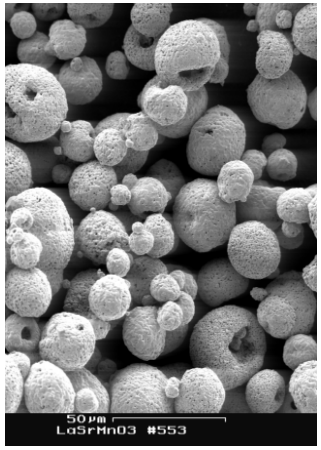
- Improvement of performance of plasma sprayed MSC
- Development of cost-effective mass production of single cells by applying plasma deposition technologies
- Transfer of optimised performance of single cells to stack operation
- Demonstration of a robust, compact and very rapidly heated SOFC stack for mobile application

Powders Used for the Spraying of the Cells

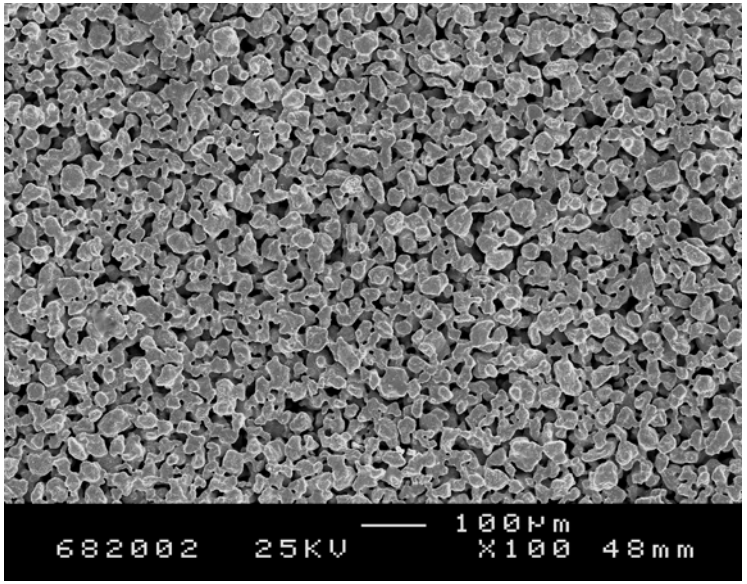
Powder	NiO	ZrO_2- 7 mol %Y_2O_3	ZrO_2- 10 mol%Sc_2O_3	$(La_{0.8}Sr_{0.2})_{0.98}$ MnO_3
Short name	NiO	YSZ	ScSZ	LSM
Morphology	sintered, crushed	sintered, crushed	sintered, crushed	sintered, spherical
Size distribution	10-25 µm	5-25 µm	2-35 µm	20-40 µm
Supplier	Cerac, USA	Medicoat, Switzerland	Kerafol, Germany	EMPA, Switzerland

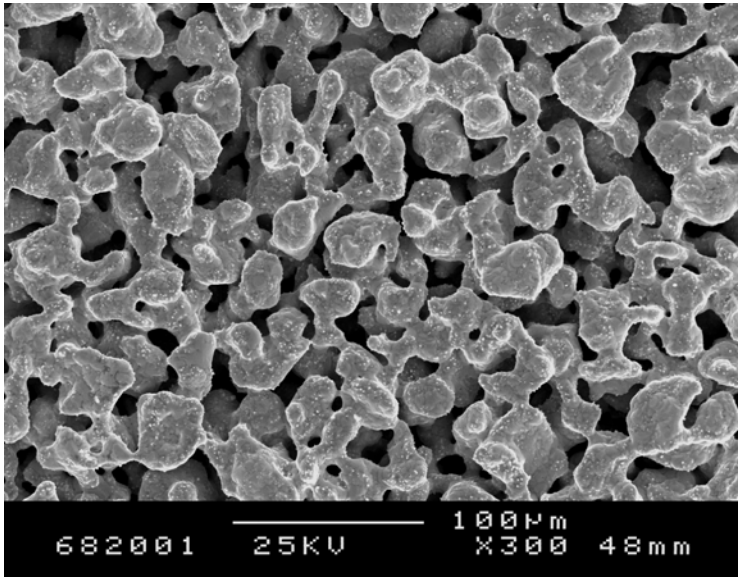




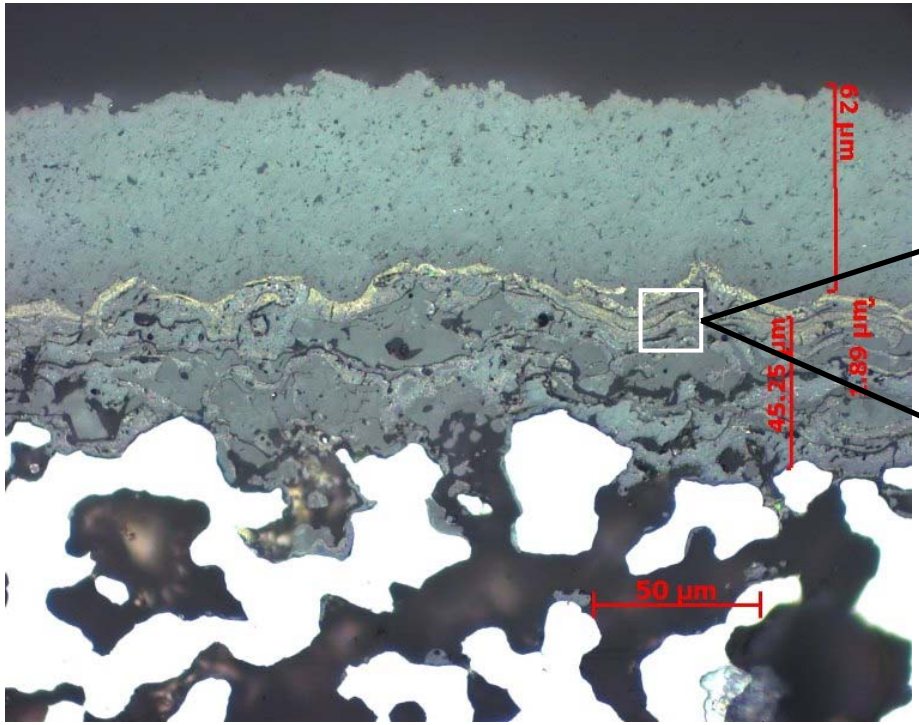


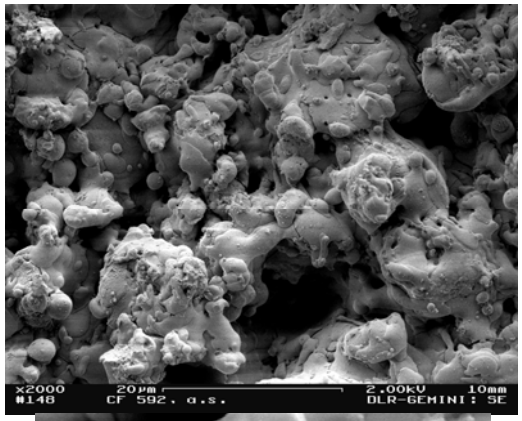
Morphology of Porous Metal Substrate PM Fe-26Cr-(Mo,Ti,Mn,Y_2O_3) of Plansee SE

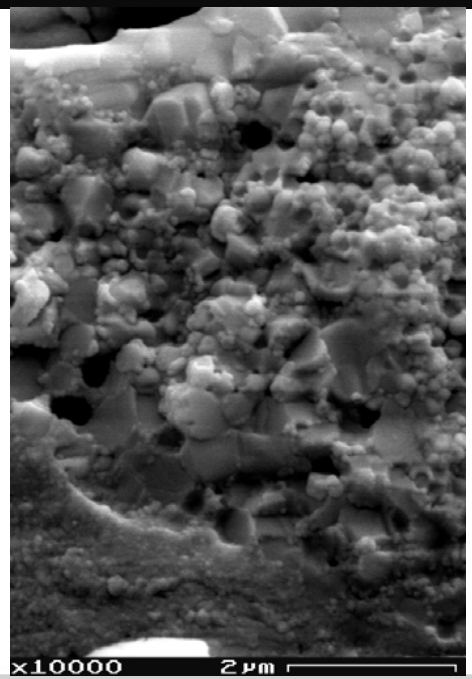




Development of Nanostructured Anode Layer



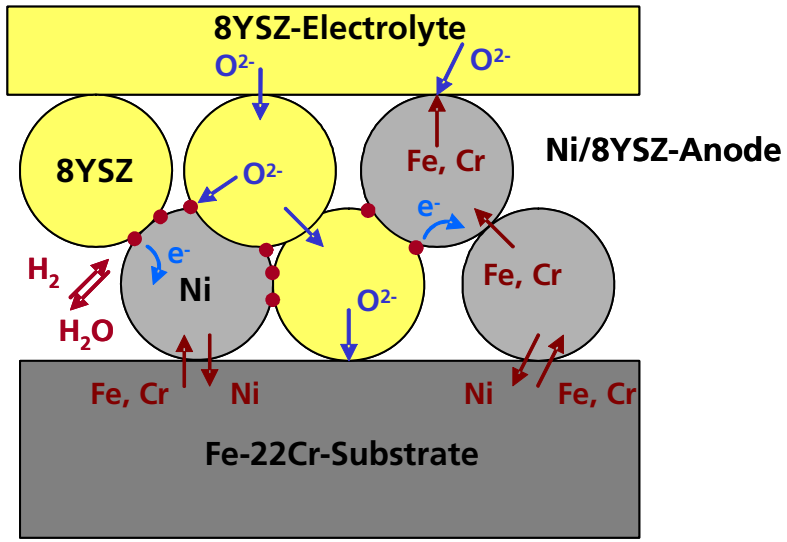




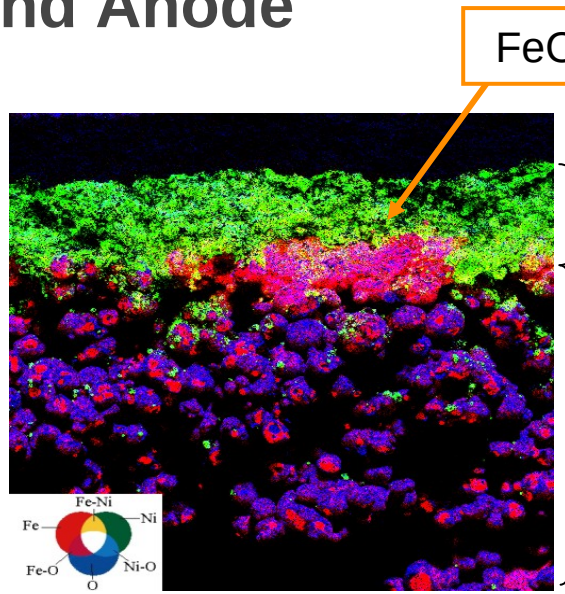
Permeability coefficient (10^{-15} m^2)

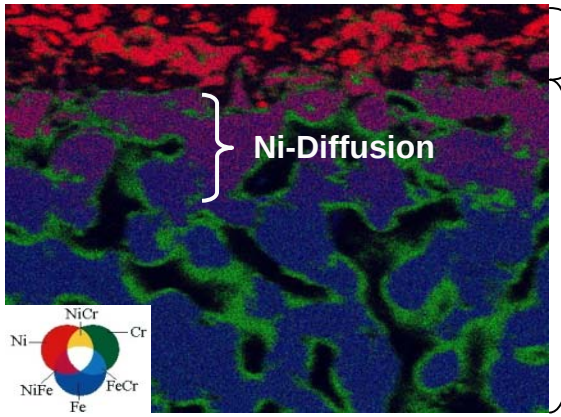
VPS ref	APS conv.	Ni-C	Double Layer
2	12	30	54

Interdiffusion of Fe, Cr and Ni Between Substrate and Anode

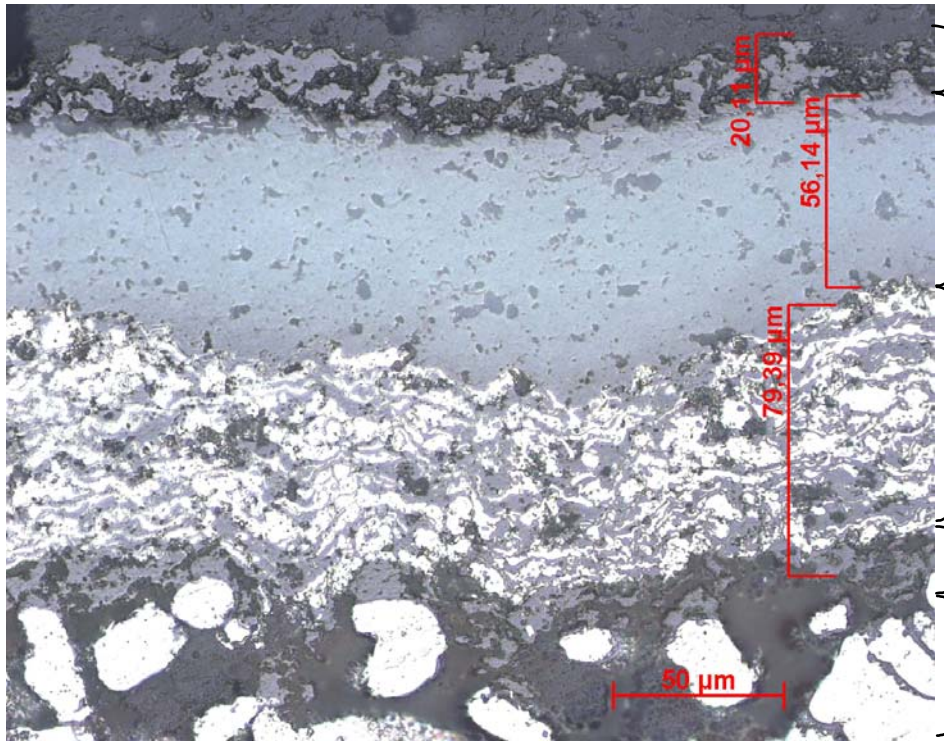


- Triple phase boundary (TPB)





Metallographic Cross Section of MSC Cell



$LaSrMnO_3$-cathode

8YSZ-electrolyte

Ni/8YSZ-anode

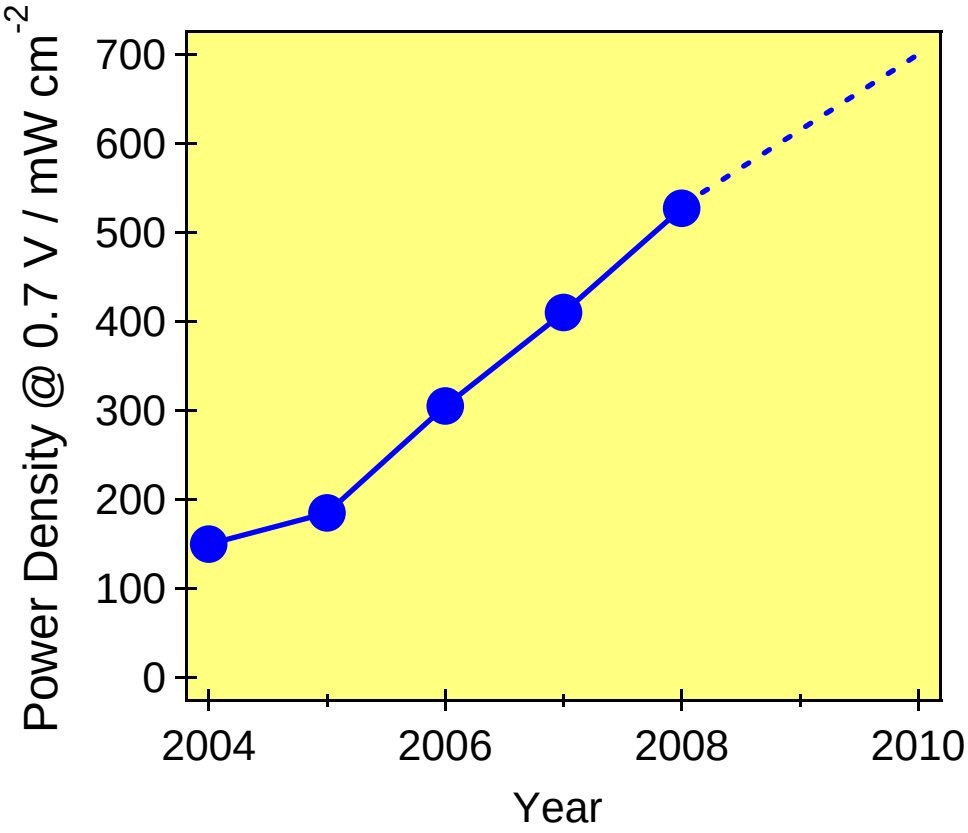
Perovskite-type barrier layer

Porously sintered ferrite plate

Development of Cell Performance at DLR

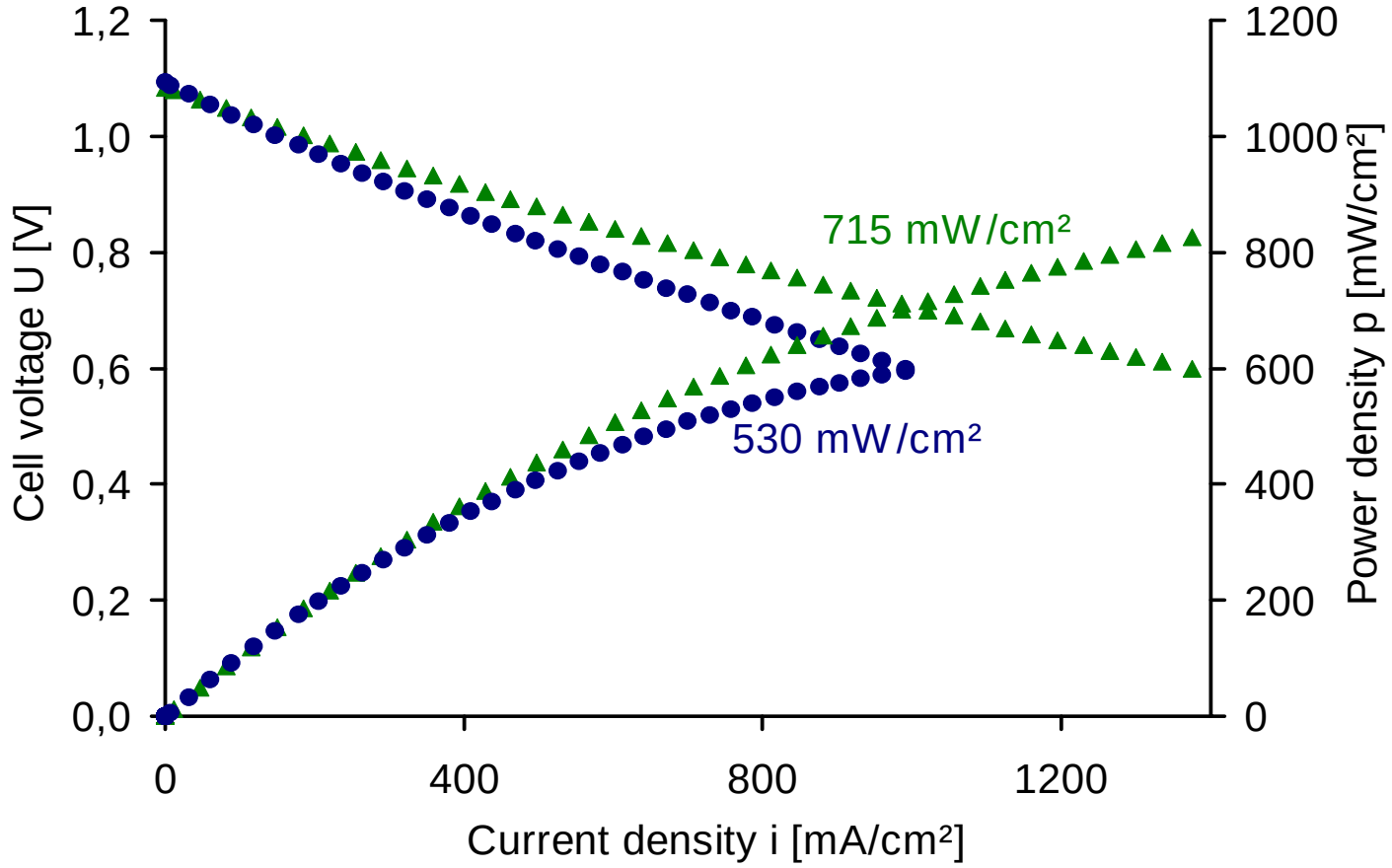
Metal Supported Cell:

Improved power density through
- Functional layer development
- New materials

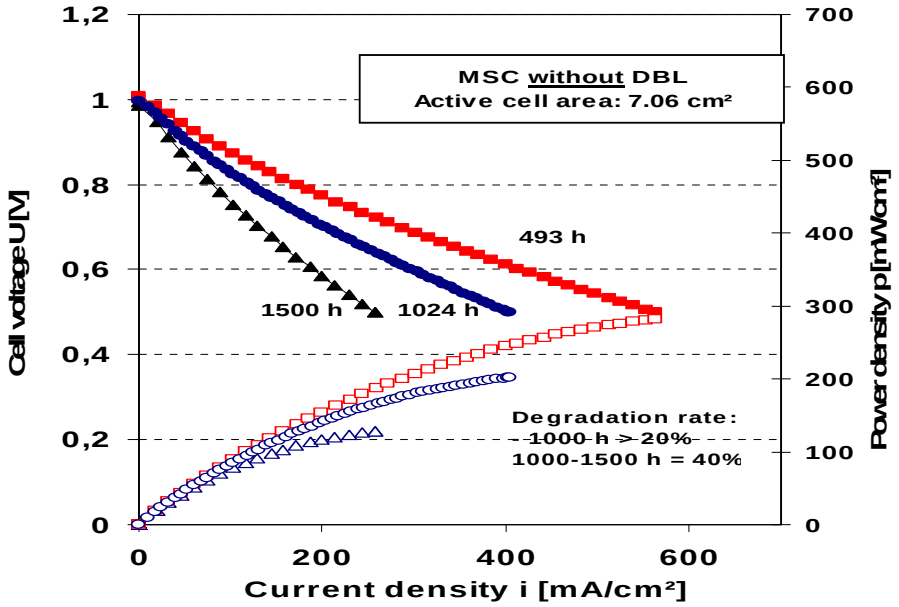


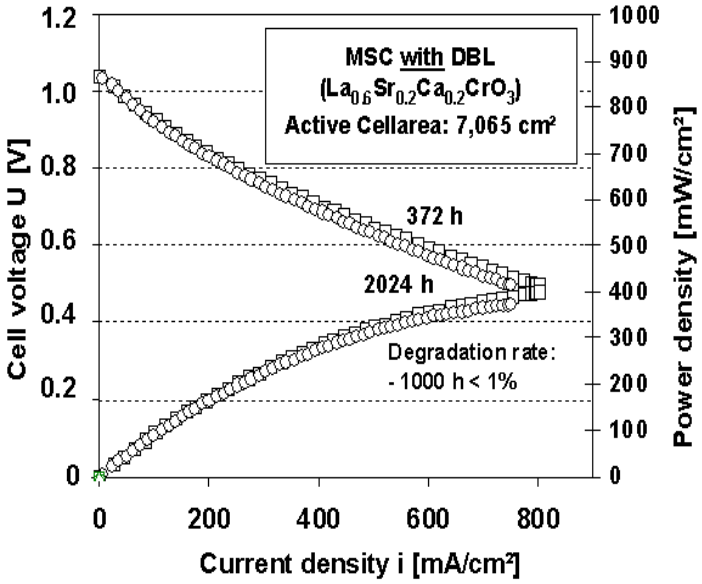
Electrochemical Performance of MSC Cell at DLR

(Active area: 12 cm²)

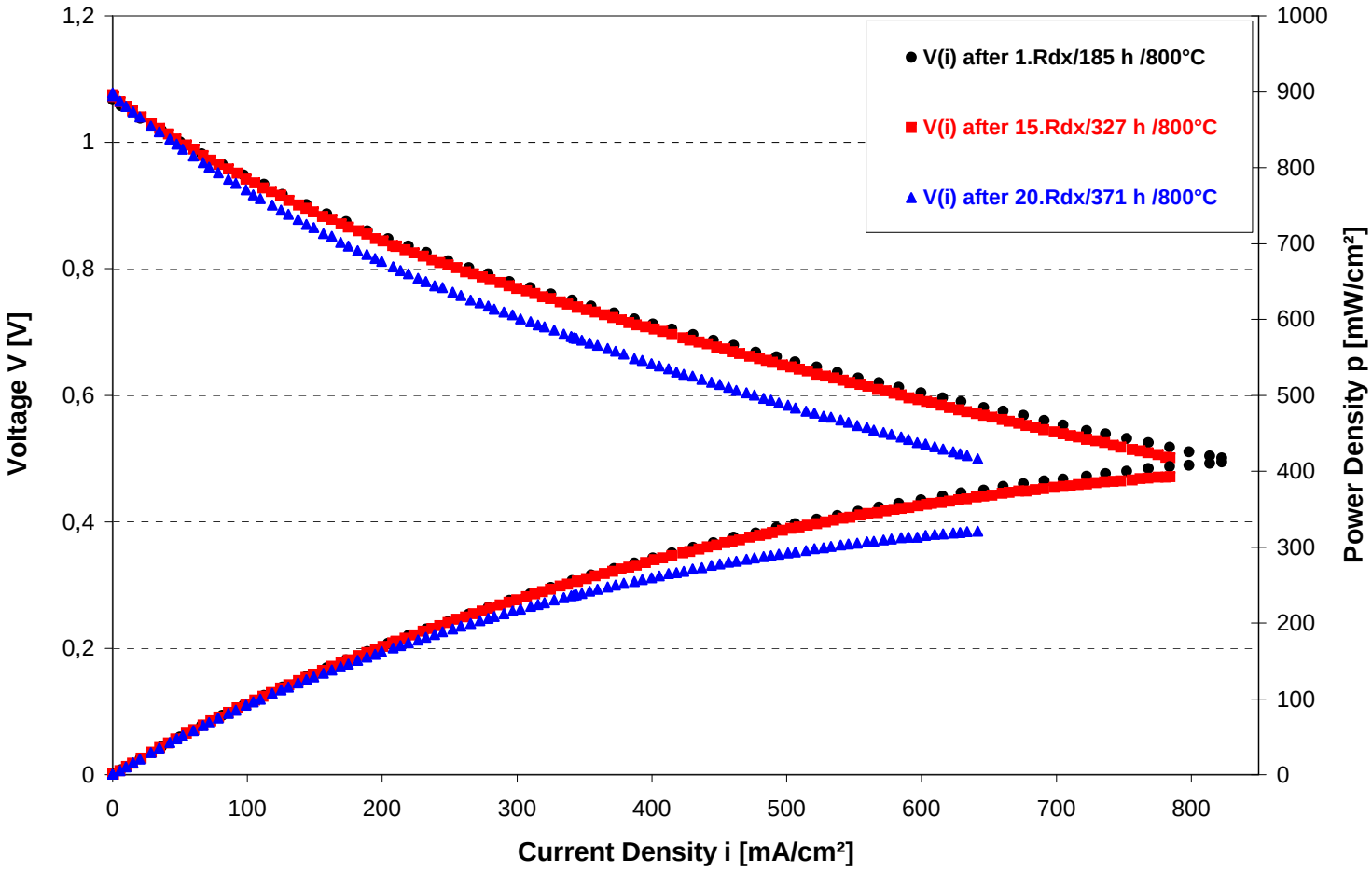


Electrochemical Performance of VPS Cells With and Without Diffusion Barrier Layer in Operation with Simulated Reformate H2/N2 and Air



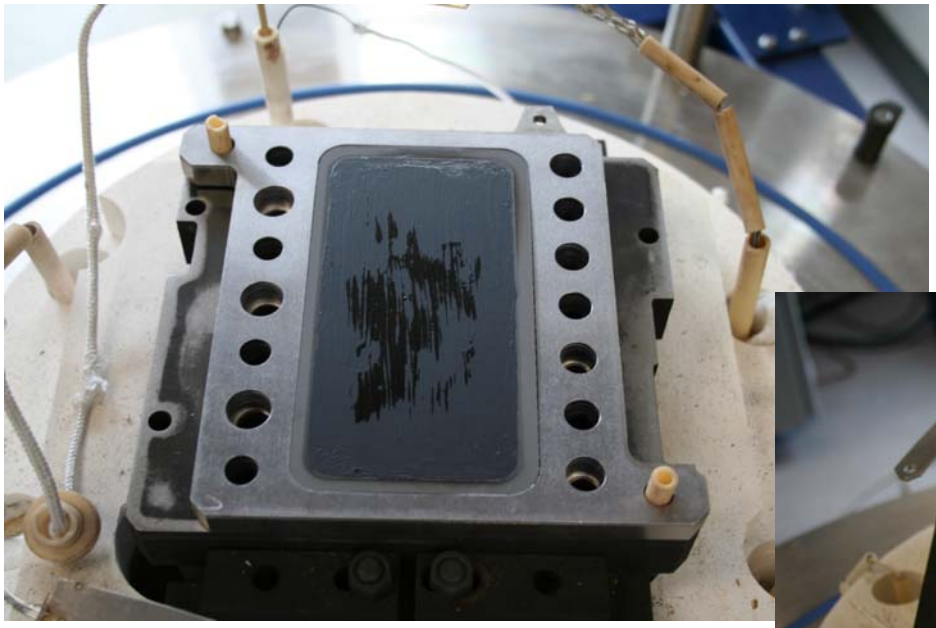


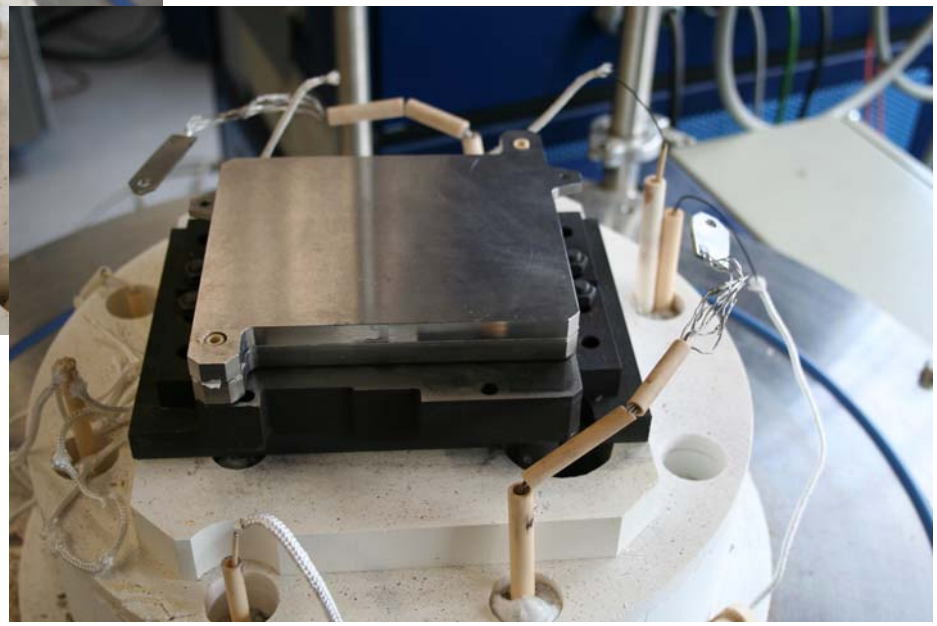
I-V Characteristics of a VPS Cell after Redox Cycling



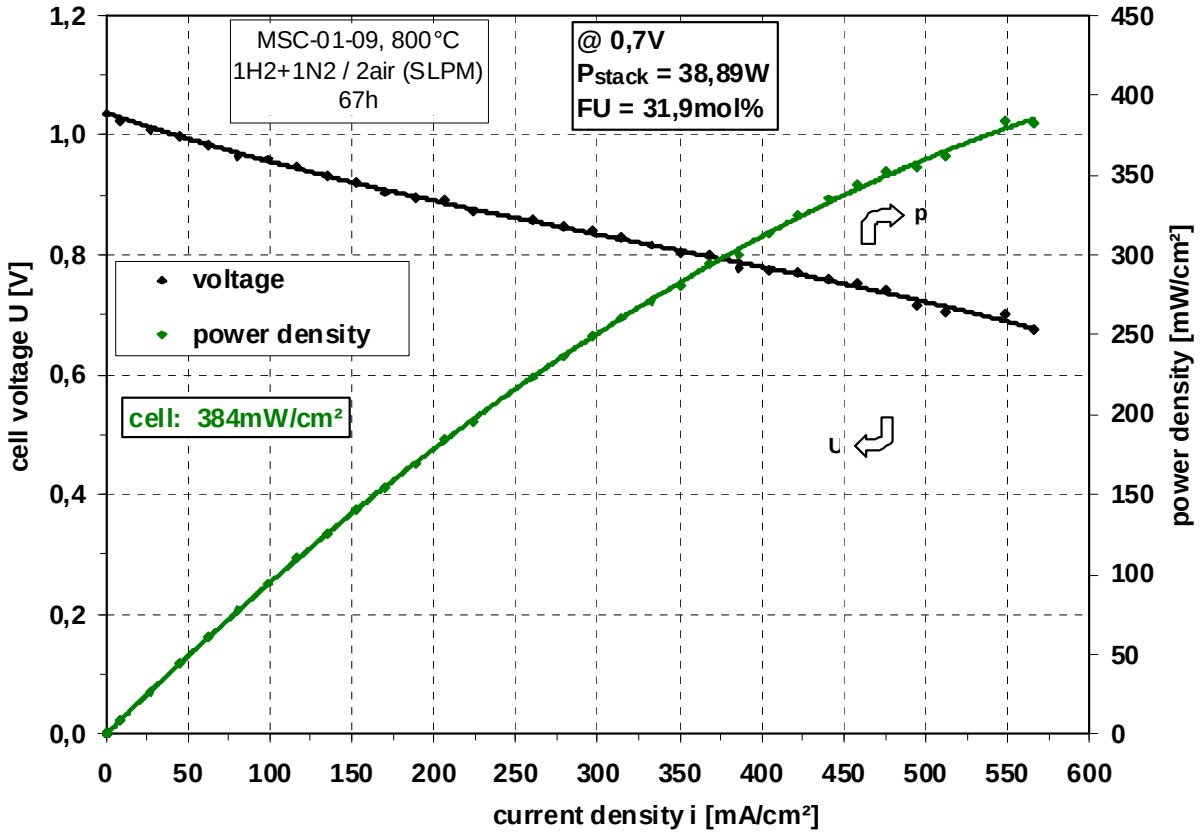
Short Stack Assembly of Full-Scale Cells

(Active area: 84 cm^2)





Electrochemical Performance of Full-Scale MSC Cell



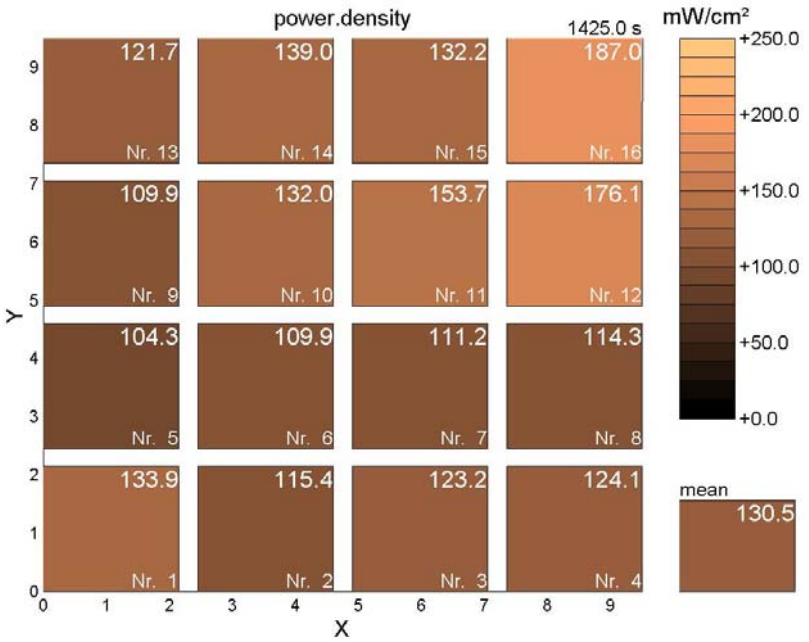
Motivation for Spatially Resolved Cell Characterisation

Problems:

- Strong local variation of gas composition, temperature, and current density

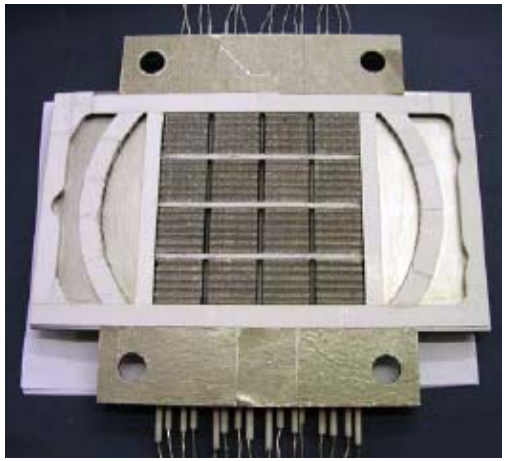
This may lead to:

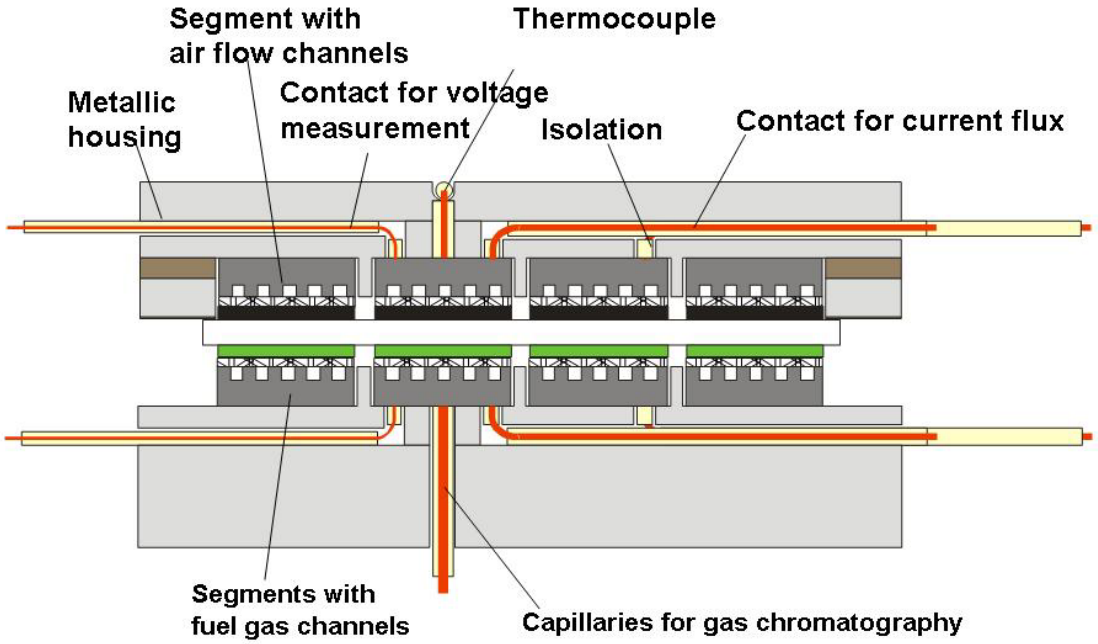
- Reduced efficiency
- Thermomechanical stress
- Degradation of electrodes



Effects are difficult to understand due to the strong interdependence of gas composition, electrochemical performance and temperature

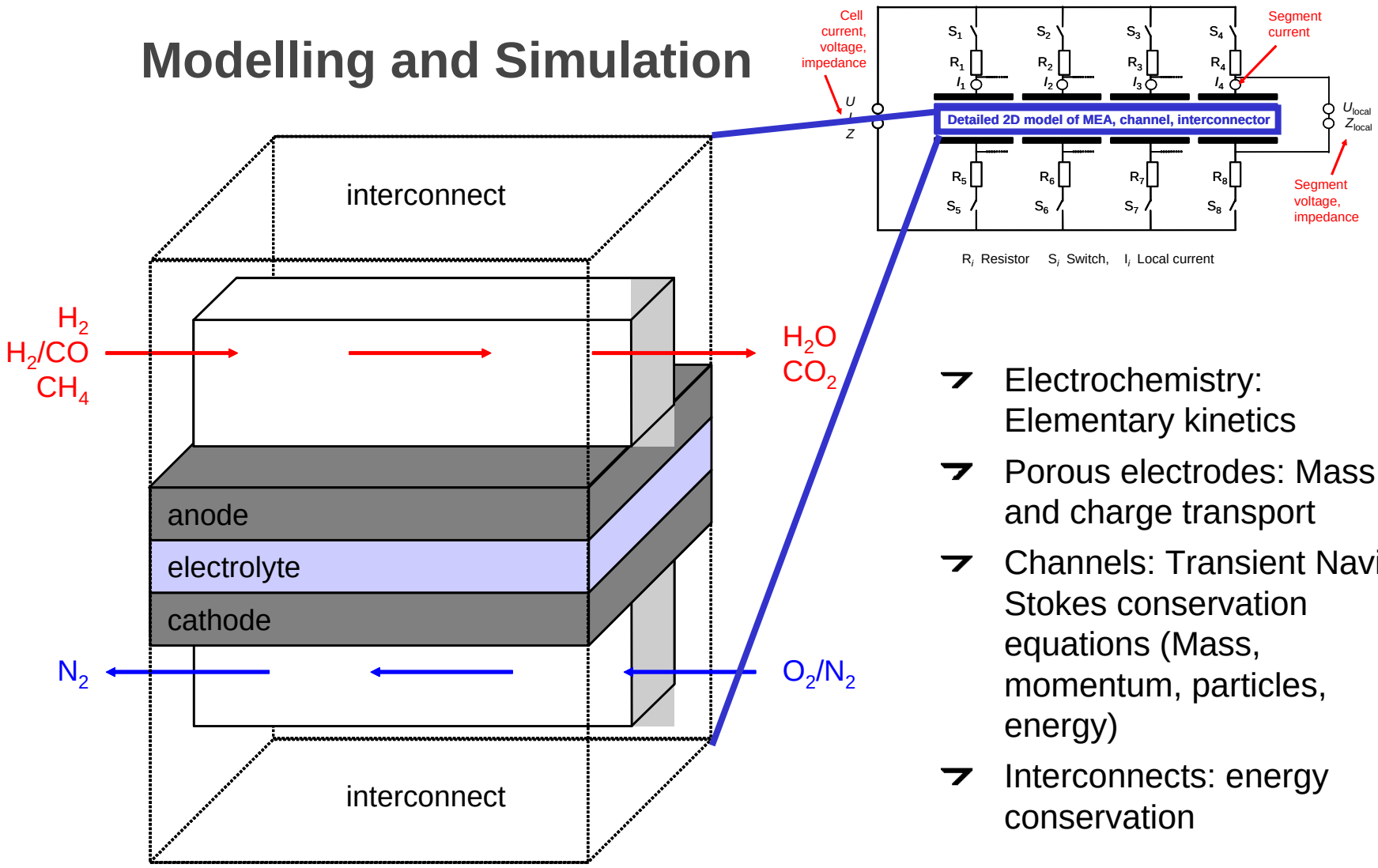
Measurement Setup for Segmented Cells





- 16 galvanically isolated segments
- Local and global i-V characteristics
- Local and global impedance measurements
- Local temperature measurements
- Local fuel concentrations
- Flexible design: substrate-, anode-, and electrolyte-supported cells
- Co- and counter-flow

Modelling and Simulation

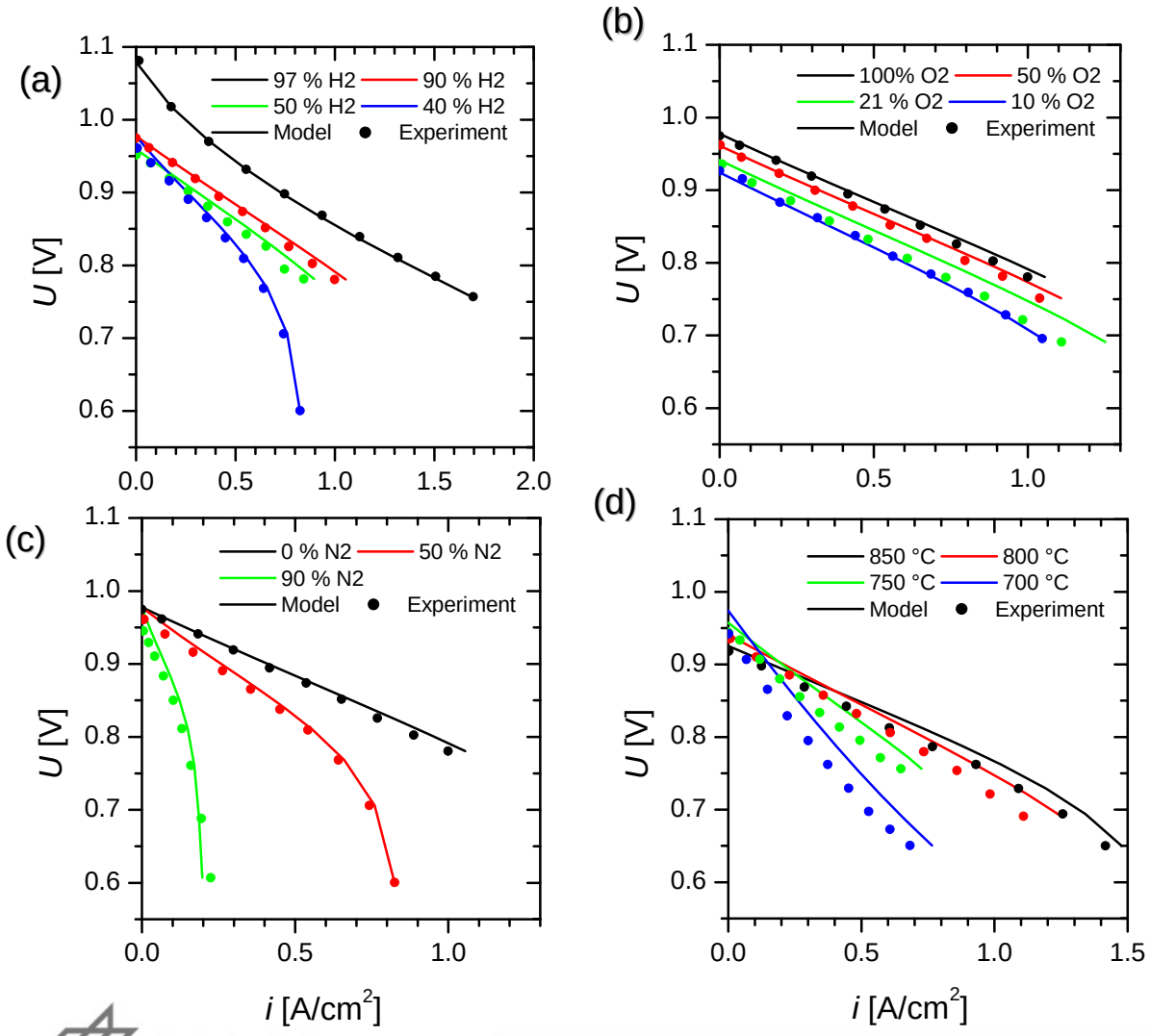


- Electrochemistry: Elementary kinetics
- Porous electrodes: Mass and charge transport
- Channels: Transient Navier-Stokes conservation equations (Mass, momentum, particles, energy)
- Interconnects: energy conservation

W. G. Bessler, S. Gewies, and M. Vogler, Electrochimica Acta 53, 1782-1800 (2007)

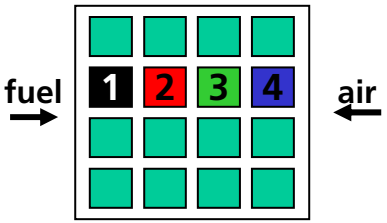
Model validation

- 1D model, single segment, low fuel utilization

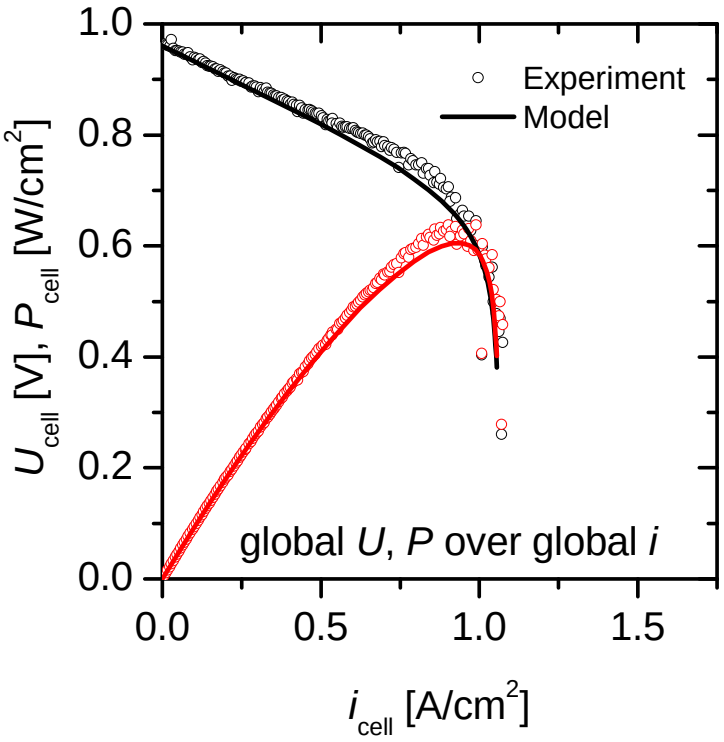


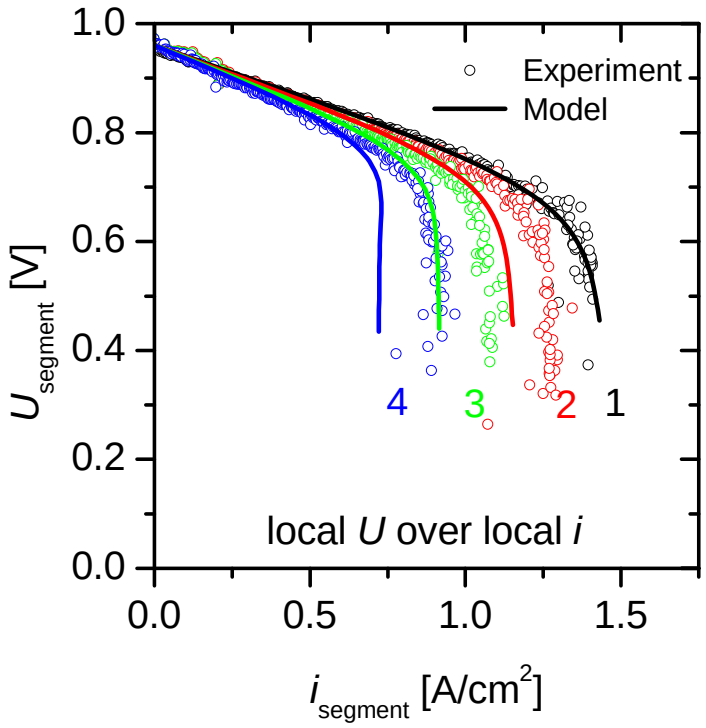
- Good agreement between model and experiment
- Cell degradation is observed

Full measurement and 2D simulation



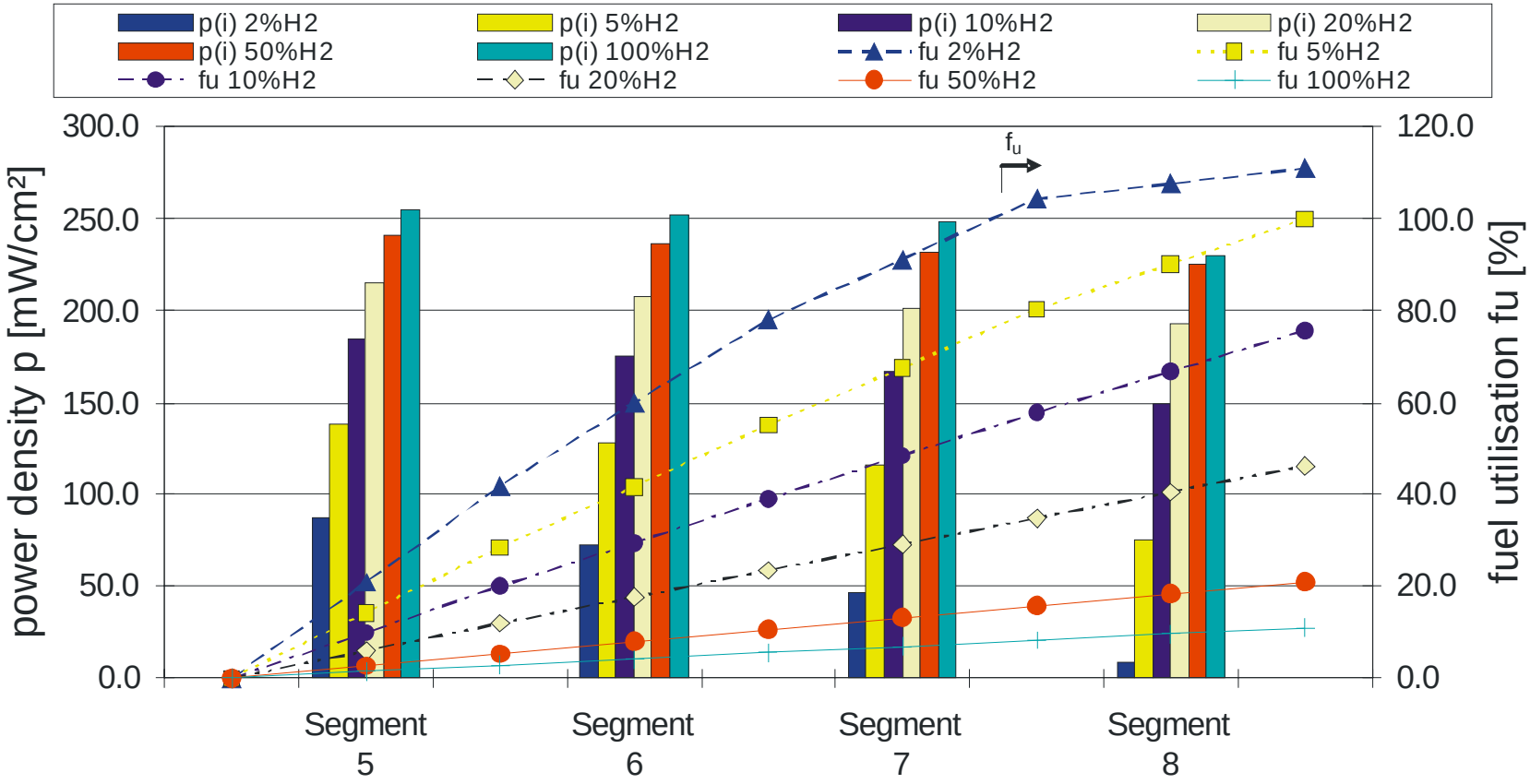
- Anode: 50% H_2, 50% H_2O, fu_{max}= 60%; cathode: 50% O_2, 50% N_2



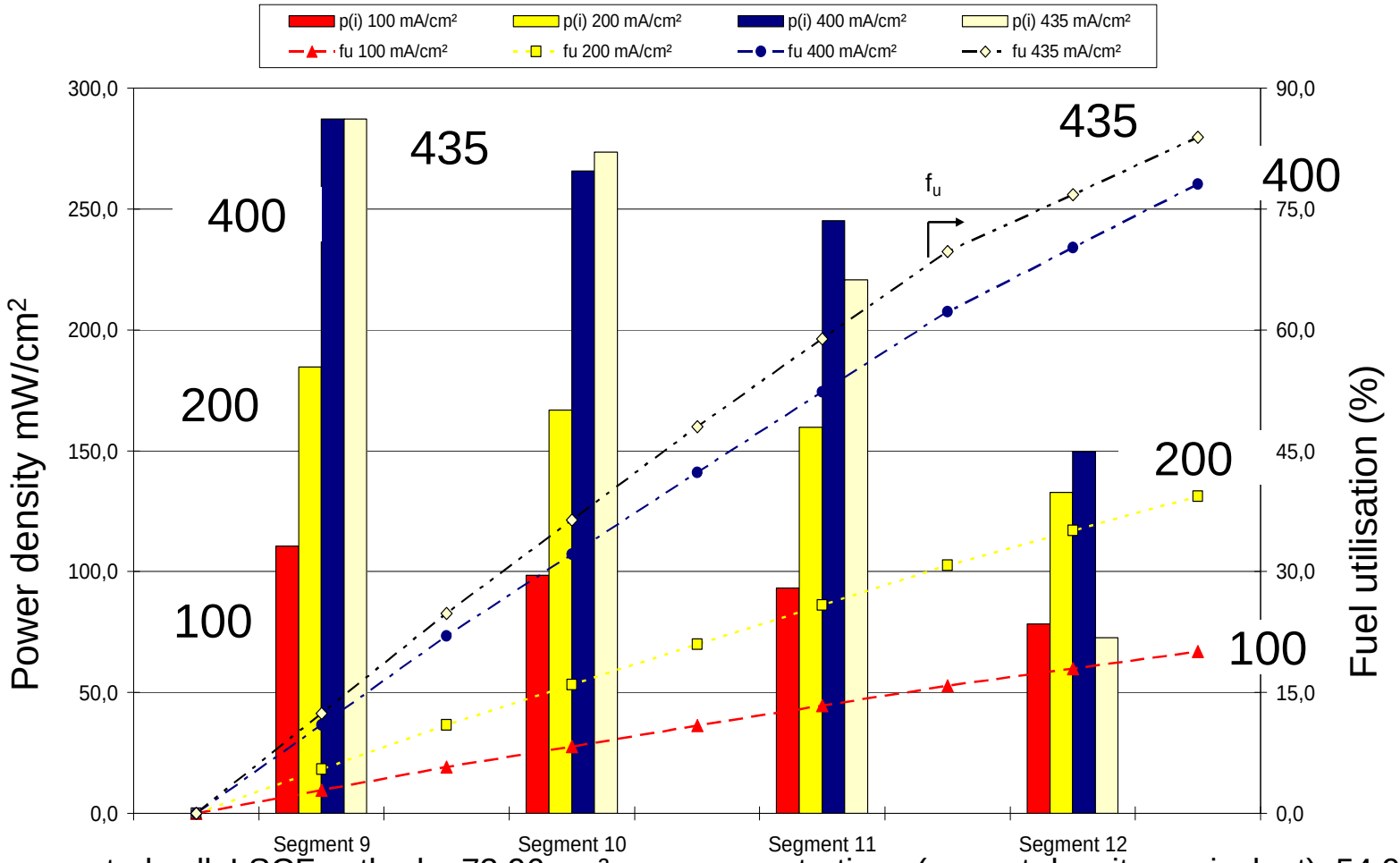


- Simulation is in qualitative agreement with experiment

Locally Resolved Power Density Distribution and Fuel Utilisation in Dependence of H_2 Concentrations

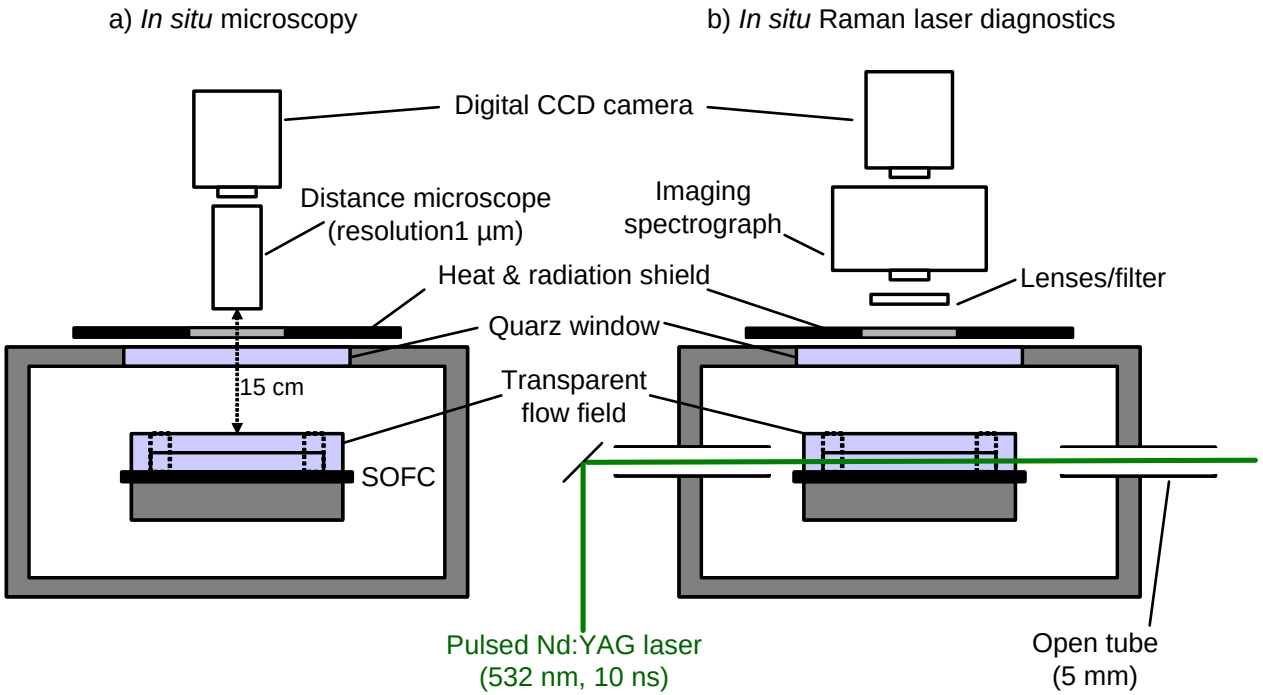


Variation of Load - Reformate

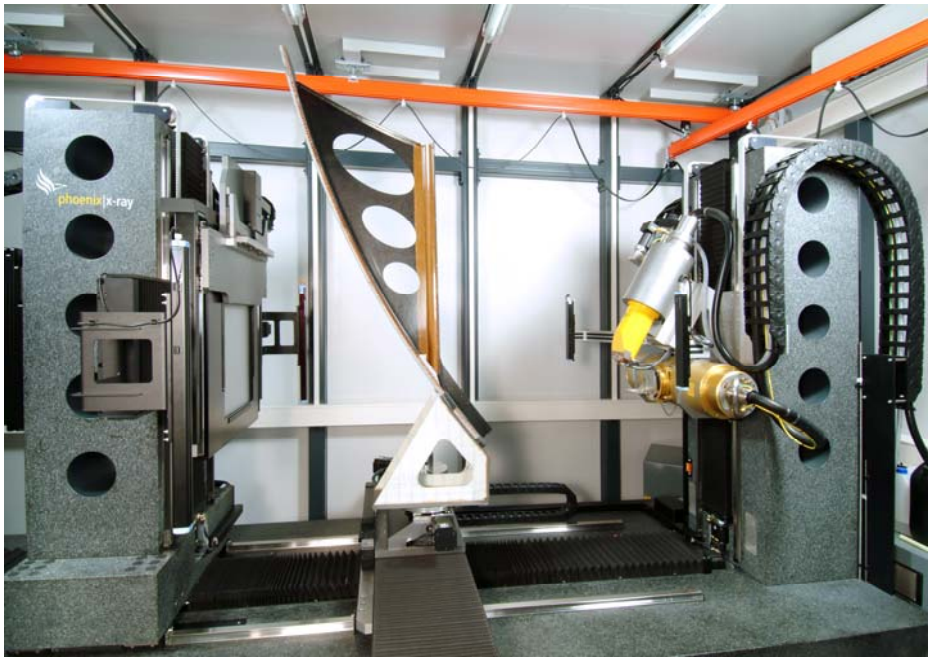


Anode supported cell, LSCF cathode, 73,96 cm², gas concentrations (current density equivalent): 54.9% N_2, 16.7% H_2, 16.5% CO, 6,6% CH_4, 2.2% CO_2, 3.2% H_2O (0.552 A/cm²), 0.02 SlpM/cm² air

Potential for Optical Spectroscopies

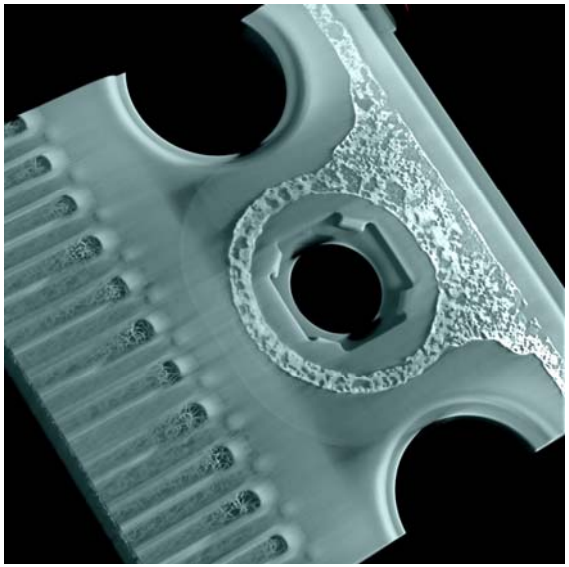


X-Ray Tomography (CT) Facility at DLR



X-Ray CT Facility v|tome|x L450 at DLR Stuttgart

3 dimensional non intrusive imaging of SOFC cassette



Conclusions

- The development of the metal supported SOFC concept has a high potential for SOFC application in dynamic operation with multiple thermal and redox cycles
- Scale-up to a full size cassette with adequate cell performance is under way
- The industrialisation of the MSC concept is conducted within an industrial consortium
- Spatially-resolved measuring techniques are important analytical tools to optimise cell operation
- Experimental data are obtained using a segmented cell setup that allows for the measurement of local i-V characteristics, gas composition and temperature
- Simulations under realistic operating conditions showed strong gradients of gas concentrations and current density along the flow path and through the thickness of the membrane-electrode assembly